Processing for Autonomous Operation

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Outline of Presentation

- Vision & challenges
- Research Issues:
  - Navigation & Control
  - Efficient information extraction
  - Collaborative Processing
  - Networking
- Conclusions

Autonomous Processing Vision

Semi- & fully autonomous micro-systems that are capable of:

- **Multi-modal sensing**
- **Mobile networking**
- **Distributed signal processing and fusion**
- **Group collaborative behavior and navigation**
- **Learning and consensus building**
- **Survival and extended lifetime**
- **Interface with, and take advantage of, macro-level systems**

Under micro-platform limitations on weight, power, bandwidth, and mobility.

Example Research Topics

Micro Autonomous Systems and Technology

Microsystem Mechanics

- Platform stability & control
- Low Reynolds number aerodynamics
- Bio-inspired sub-systems
- Propulsion and linear actuation
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Processing for Autonomous Operation

- Autonomous navigation and control
- Efficient information extraction and utilization
- Dynamic collaborative processing
- Cross-layer communications and network design
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Microelectronics

- 3D materials and circuit architectures
- Sensors and actuators for platform and payload
- Smart, multifunctional materials
- Low power devices and small electric power management
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Platform Integration

- Microsystem architectures, modeling, and design tools
- Experimentation and analysis
- Sub-system interactions
- Multi-functional packaging
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Challenges - 1

- **Mobility, sensing, processing, & comms *per Joule***
  - **tight coupling across architecture and function**
- **Differentiating size, weight, power, performance regimes**
  - **fundamental and technology limits**
- **Lifetime & associated tradeoffs**
- **Sensor & information utility, and bandwidth constraints**

Challenges - 2

- Heterogeneous nodes, modularity, architecture
- Intra- vs inter-node processing & communications load
- Degree of reliance on centralized network & processing
  - robust communications and networked control
- Ultimately: Exploration and complex group behaviors in unknown environments

Example Complex Behaviors

- Map & navigate
- Interact with mothership
- Search & identify, follow
- Cooperative sensing & communications
- Collaborative behavior:
  e.g., deliver battery, provide comms relay, verify medical condition
- Hide & perch, trip wire
- Extend lifetime via sleep

Ex. Research Issues, Auton. Nav & Control

- Span *Command & Control* to *Connect & Collaborate*

- Human interface, semi-autonomy, full autonomy
- Position (geolocation) and synchronization
  event timing, navigation, communications
- Exploration & Navigation
  active *vs* passive sensing, mapping
- Control architecture & communications interplay
  distributed *vs* centralized robust control
- Bio-inspired paradigms

Ex. Res Issues: Info Extraction & Utilization

- **Integrated efficient intra-node sensing and processing**
- **Multi-modal sensor utility**

  power, processing load, bandwidth tradeoffs
- **Energy efficient information extraction and reduction**

  e.g., sufficient statistics, compression
- **Sensor, controller, actuator management**

Balance intra-node information extraction and reduction versus communications cost.

Ex. Res Issues: Dynamic Collab. Processing

- **Balance distributed sensing, distributed processing, and communications load**
- **Distributed consensus building**
- **System utility *vs* lifetime**
- **Interaction with macro-level system(s)**
- **Cooperative group behavior**

  e.g., exploiting mobility

Ex. Res Issues: Communications & Networking

- Fundamental limits and analytical design techniques unknown
- Network architecture, heterogeneous nodes
- Adaptive networking, cooperative comms, relays
- Network set-up and maintenance
- Radio:
  - Analog / digital, complexity vs robustness & security
  - small RF aperture, antennas
  - propagation, penetration, wavelength
- Communication modalities (e.g., acoustic, optical)
- Dual sensing & comms modalities
  - implicit communications, e.g., through (in-) action

Principles of MAST Processing

Balance communications load against performance.

Integrate networking, positioning, navigation, & control.

Integrated resource management, and lifetime extension.

Tight coupling with devices & technology, seeking fundamental (and achievable) limits and tradeoffs.

Adapt to different size/weight/power regimes.

Balance autonomy, human, and machine interaction.

Power and energy savings critical.